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Volume II – Preliminary Analyses and Conceptual Design

By Program Development

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because the resultant sun angle, β, equaled 23.5 plus the orbital inclination. For this nodal orientation of 180 degrees, a 45 degree inclination would yield 100 percent sun illumination for a continuous period of time. Orientation of 90 and 270 degrees does not allow the sun angle to build up as the orbital inclination increases; this results in a nearly constant occultation time versus inclination.

Maximum and minimum occulted time associated with orbital inclinations of 0, 28.5, 55, and 90 degrees is given in Table III-4 for an altitude of 270 nautical miles. Maximum occultation occurs when the sun angle is zero and this condition will occur for any inclination; therefore, a constant time of 35.8 minutes for all inclintations is shown. Zero occultation time would occur with the 55 and 90 degree inclinations; as depicted in Figure III-17, an inclination greater than 45 degrees would result in zero occultation over a continuous period of time during a year's span.

TABLE III-4. EARTH OCCULTATION OF SUN FROM EARTH ORBIT FOR AN ORBITAL ALTITUDE OF 270 NAUTICAL MILES AND AN ORBITAL PERIOD OF 94.6 MIN

	Orbit Inclination (degrees)			
	0	28.5	55	90
Maximum Time Occulted Orbit (min)	35.8	35.8	35.8	35.8
Minimum Time Occulted Orbit (min)	34.5	27.4	0.0	0.0

2. Target Source Viewing Accesibility.

a. Background Comments. For analysis relative to the HEAO, there are two primary sets of inertial coordinate systems, the equatorial system and the ecliptic system. The intersection of the equatorial and ecliptic planes as the apparant motion of the sun crosses the equator from south to north is the positive X-axis for both systems. The position of a source is identified in the equatorial system by two angles: right ascension, α, and declination δ. The angle α is measured counterclockwise from the X-axis to the projection of the source into the equatorial plane; δ is the angular distance from the source to the equatorial plane. The two angles in the ecliptic system are the celestial longitude, λ, and celestial latitude ϕ. The longitude and latitude are measured in a similar manner as the right ascension and declination with the ecliptic plane being the reference plane.

This section presents the results of analysis displayed in the two different coordinate systems for determining the opportunity to view a source, first, for a given date to determine the accessible viewing area and locate target sources within this range and, second, for a given source to determine the length of time it will present viewing opportunity for the pointing spacecraft. Also presented is the amount of time a source will be occultated by the earth for a 270 nautical mile altitude and 28.5 degree inclination orbit.

b. Target Source Viewing Opportunity

(1) Determination of Areas Within View on a Given Date. The coordinate of a target source is usually given in the equatorial coordinate system: right ascension, α, and declination, δ. However, the presentation of information relative to the viewing opportunity of the source is more conveniently displayed in the ecliptic coordinate system.

The spacecraft pointing direction is determined from the direction of the earth-sun line. With a 15 degree half cone angle about the sun direction, the spacecraft can view objects within a 30 degree band around the celestial sphere; the viewing band will be perpendicular to the ecliptic plane (Fig. III-18).

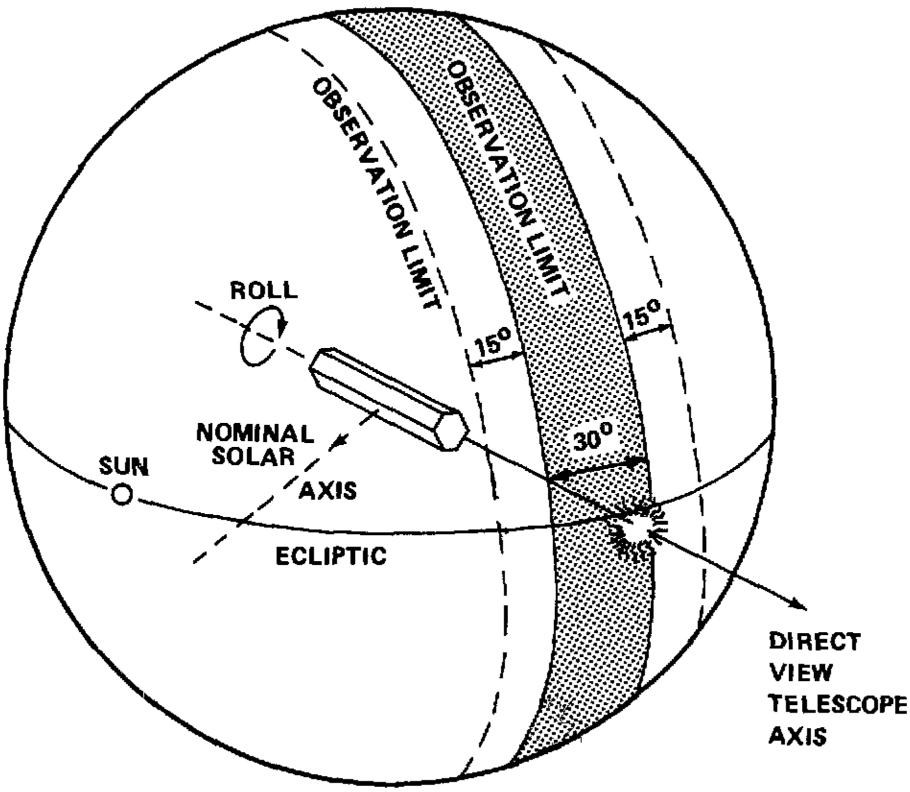

Figure III-18. Definition of ±15 degree and ±30 degree access bands.

(2) Equatorial System. Any point on the celestial sphere has coordinates equivalent to latitude and longitude. Latitude varies from -90 degrees to +90 degrees and longitude from 0 degrees to 360 degrees. For the present, the celestial sphere will be represented by plotting the right ascension as the *abscissa* and declination as the coordinate. Considerable distortion will result, but all points can be shown. Various planes that are on the celestial sphere will resemble either straight lines or sine functions.

Figure III-19 presents the celestial sphere using the equatorial coordinates, right ascension, and declination. (Right ascension is expressed in units of time rather than degrees, a common practice in astronomy; to get degrees, simply multiply hours by 15.) The galactic plane appears as a sine curve. Viewing bands for various orientations of the rotation axis are indicated by connected lettered points. The sun is in its March 21 position. The viewing plane that results when the spacecraft rotation axis is pointed directly at the sun is indicated as the "nominal" plane. The nominal ±15 degree viewing band is obtained by fixing the solar axis 15 degrees ahead and behind the sun, and 15 degrees above and below the ecliptic plane, i. e., for each off-nominal case the following coordinates are set:

Case 1:	$\Delta\lambda = +15$	$\Delta\phi = 0$
Case 2:	$\Delta\lambda = -15$	$\Delta\phi = 0$
Case 3:	$\Delta\lambda = 0$	$\Delta\phi = +15$
Case 4:	$\Delta\lambda = 0$	$\Delta\phi = -15$

If the rotation axis is allowed to assume any orientation within the 15 degree cone angle of the sun, then the viewing planes can cover any point outside of the shaded area.

Note that the nominal viewing plane for this data is a straight line perpendicular to the equator. The nominal viewing plane will not usually be perpendicular to the equator; however, on March 21 (vernal equinox) the sun is at the intersection of the equatorial and ecliptic planes so that the viewing plane is perpendicular to both. Normally, the nominal viewing plane is perpendicular only to the ecliptic.

Figure III-20 shows how the area within view would normally appear in the equatorial system. This figure is for the date June 21, which is a time when the nominal viewing plane is not perpendicular to the equator. Note that the area within view in this figure is the shaded area, rather than the open area as in the other figures.

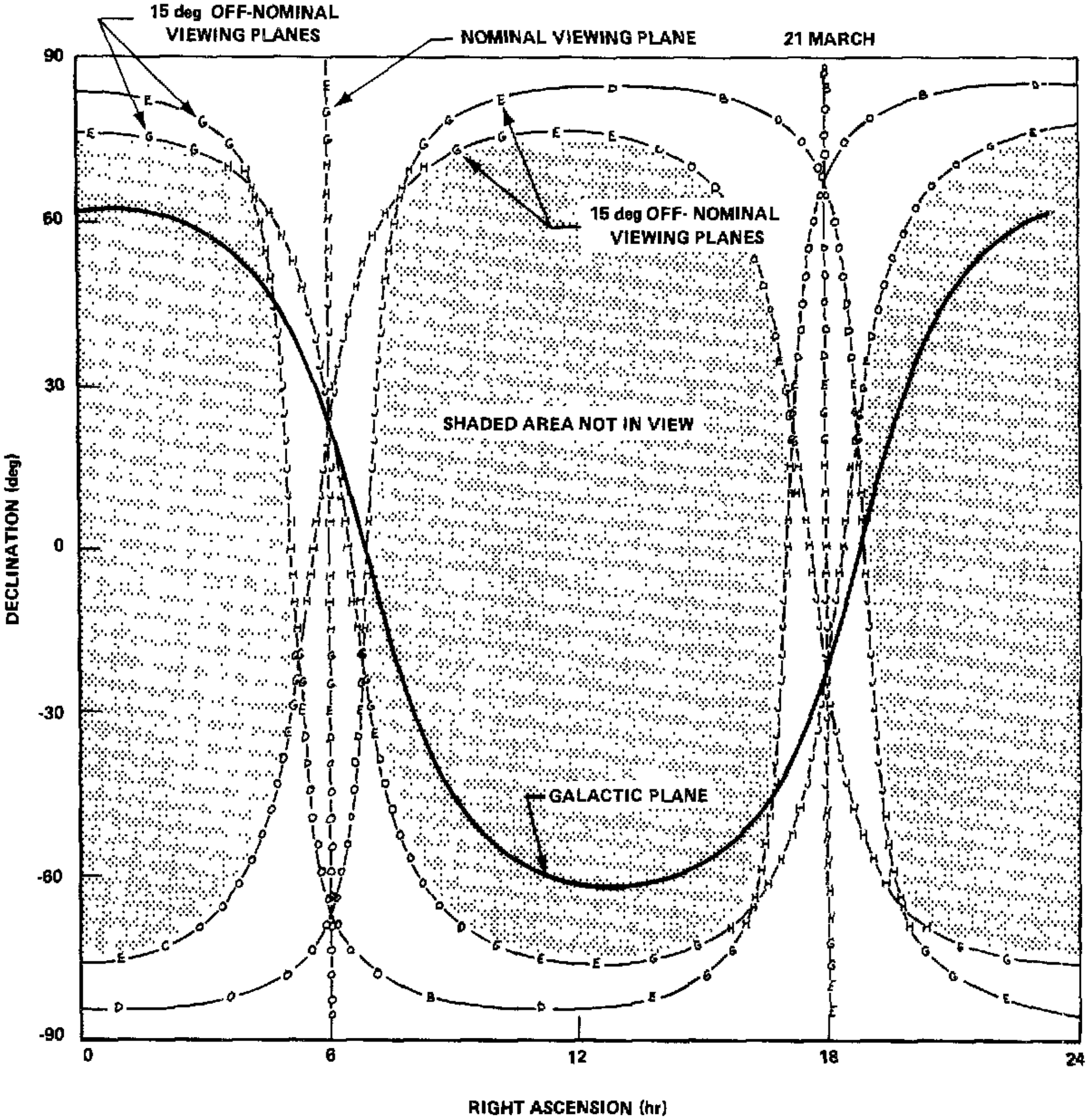

Figure III-19. Viewing planes in the equatorial coordinate system.

Note in Figure III-19 the extremely limited amount of area that would be within view if the spacecraft were not allowed any deviation from the sun line (cone angle of 0 degree). Only those points which fell directly on the nominal viewing plane could be monitored; no other points could be viewed on that date. The galactic plane is shown because it is expected that most of the sources of interest will lie close to it.

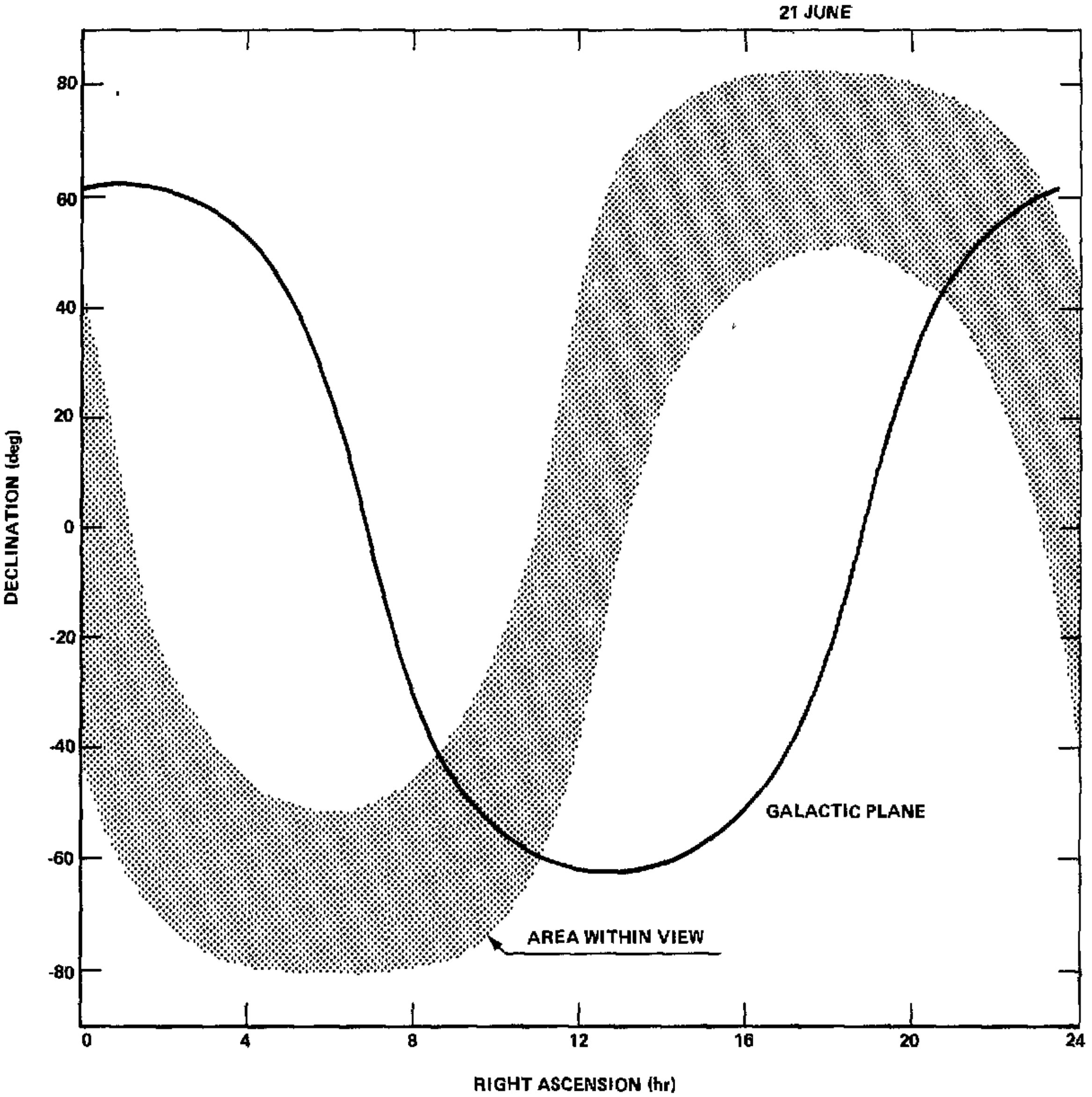

Figure III-20. Viewing area, equatorial coordinate system, 21 June.

Finally, the amount of time that each of the points would be occulted by the earth for a spacecraft in a 270 nautical mile circular orbit with inclination of 28.5 degrees and ascending node of 0 degrees is indicated by the letter used to plot the point. The following is a legend for these codes:

Range of t_0 (min)	Symbol
0	0
0 to 5	A
5 to 10	B
10 to 15	C
15 to 20	D
20 to 25	E
25 to 30	G
30 to 35	H
35 to 40	J
> 40	K

These times are good only for the specific orbit parameters mentioned. The estimation of minimum and maximum occultation time for an orbit with a given altitude and inclination will be discussed in another section. It is also assumed that if the point is within line of sight, there is no occultation; however, this may not be a valid assumption, as discussed later.

(3) Ecliptic System. The celestial sphere is shown in Figure III-21 in the longitude (λ), and latitude (ϕ) coordinate system. The viewing area accessible for March 21 is given for the 15 degree off-solar vector pointing limit. Longitudes of 90 and 270 degrees is the viewing plane obtained when the spacecraft solar axis is pointed directly at the sun. Viewing planes are shown again for four different off-solar vector pointing cases when the spin axis is 15 degrees ahead and 15 degrees behind the sun in longitude and 15 degrees above and 15 degrees below the sun in latitude. The region outside the shaded area is within the viewing disk; this results from the 15 degrees limit for off-solar vector pointing.

Most of the known high energy sources are located near the galactic plane. The projection of this plane is shown in Figure III-21. For the March 21 date, a large percent of these sources are located near 270 degrees longitude, within viewing range of the spacecraft.

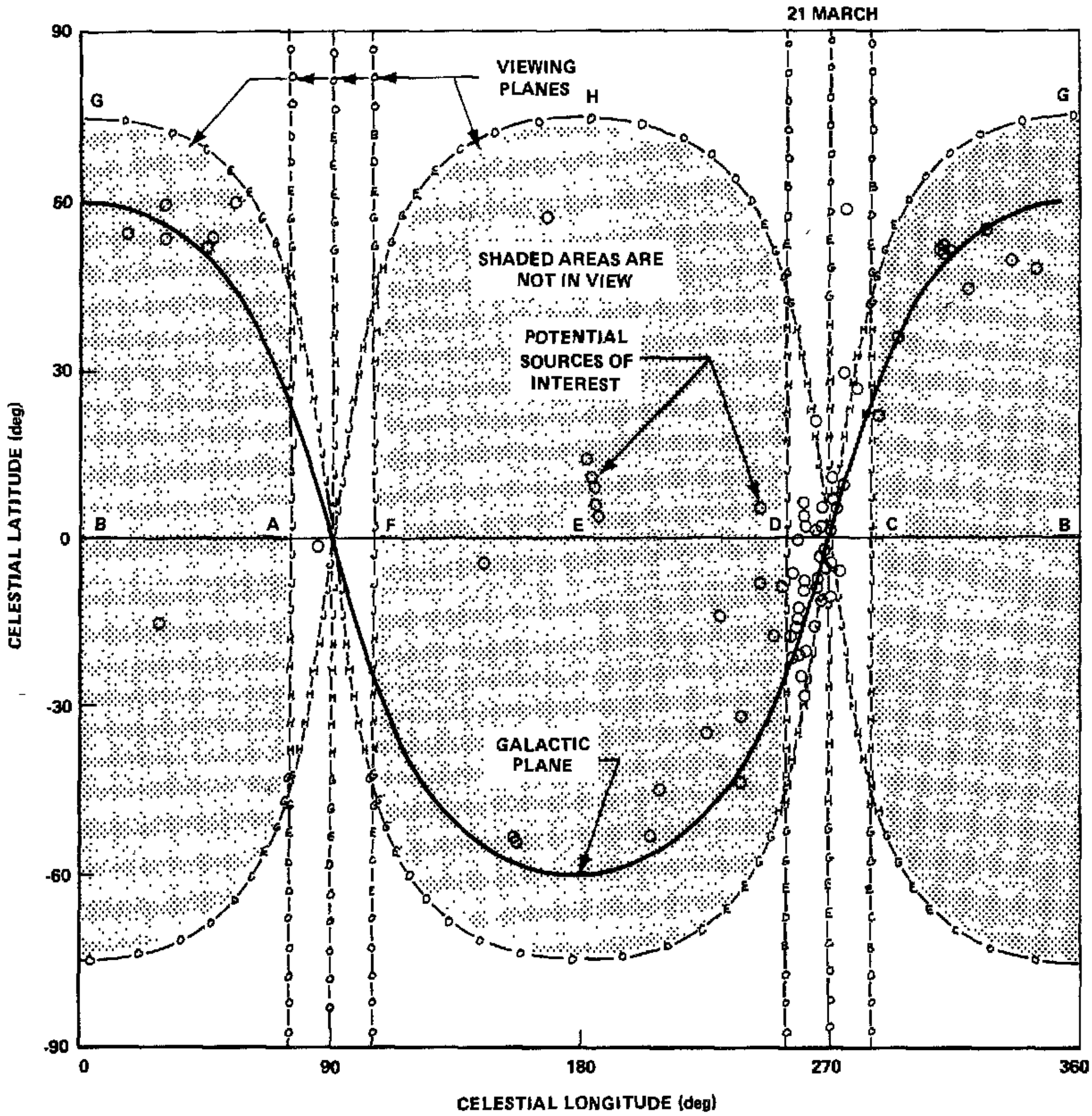

Figure III-21. Viewing planes in the ecliptic coordinate system.

The amount of time of earth occultation of the source for various latitudes and longitudes is denoted by the letters located in the different viewing bands. These occultation times are associated with a 270 nautical mile altitude, 28.5 degrees inclination, and orientation of the orbit ascending node of 0 degrees. The letter code for occultation time is the same as that given in (2).

Objects with latitude greater than 75 degrees can be seen any day during the year and still maintain an off-solar vector orientation equal to or less than 15 degrees. Figure III-22 gives the viewing area available for a given celestial longitude.

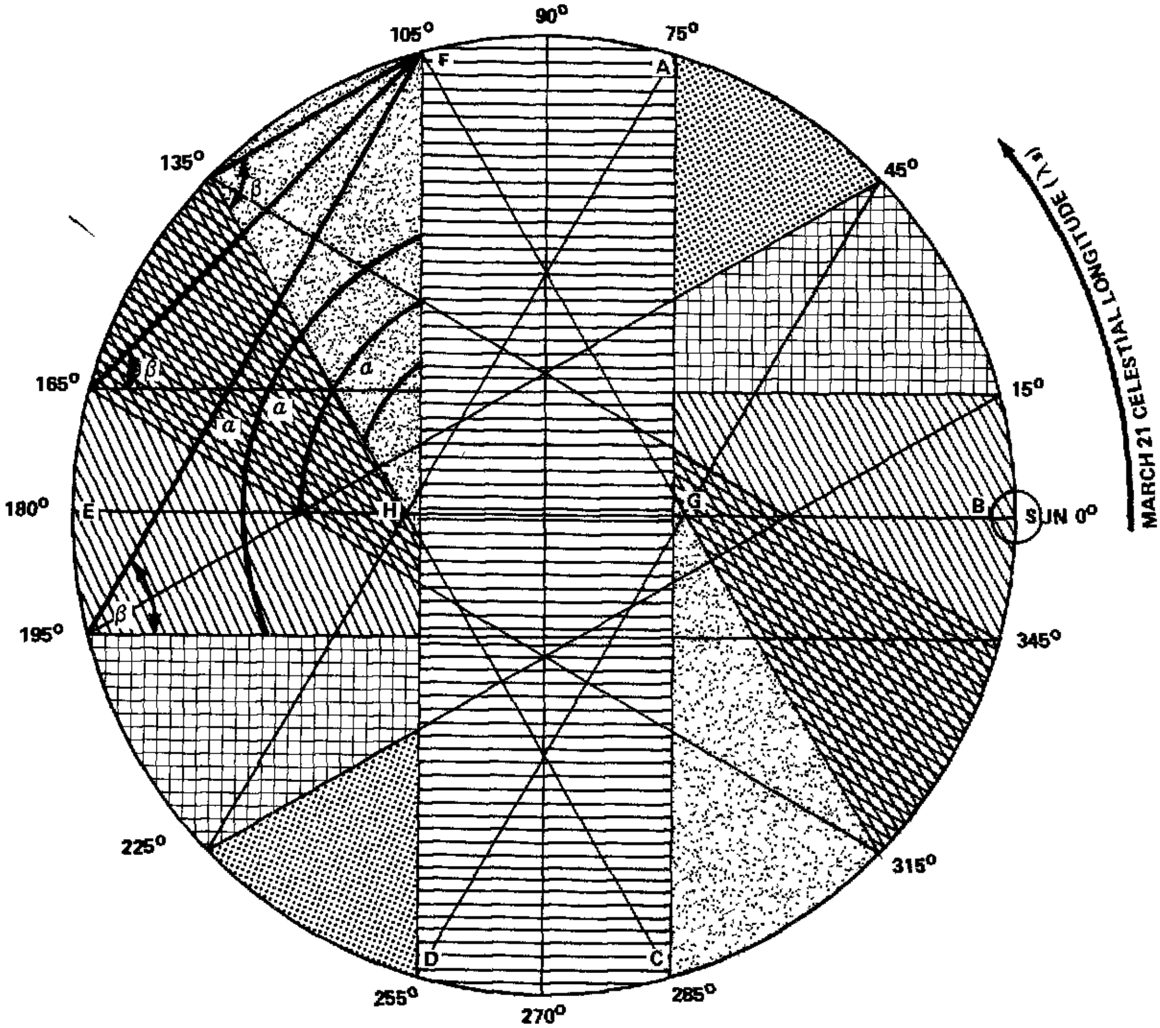

Figure III-22. Area of celestial sphere accessible to HEAO viewing.

(4) Area Exposed to Observatory's Viewing Bands. As stated previously, the nominal ±15 degree viewing band is obtained by fixing the solar axis 15 degrees ahead and behind the sun and 15 degrees above and below the ecliptic plane. The area enclosed by this band, projected onto the celestial sphere for the March 21, is denoted by area A C D F in Figure III-22. This

figure shows a view of the celestial sphere as an observer would view it standing at the north ecliptic pole. As stated previously, it is very difficult to present a spherical surface in two dimensions and as a result, Figure III-22 has a certain amount of distortion in it. This distortion is most prevalent where straight lines drawn in two dimenstions should, in fact, be curved lines in three dimensions. In light of this fact, close observation shows that the area represented by ABG, CBG, AFGH, DCGH, FHE, and DHE in Figures III-21 and III-22 are the same areas in both figures.

In spite of the distortion prevalent in Figure III-22, the problem of finding the cumulative area which the Observatory will have had access to on a given day is facilitated by the fact that the surface area of a unit sphere is proportional to the area of its Great Circle.

The area of the celestial sphere accessible for viewing by the Observatory during the day of viewing is indicated by area FACD of Figure III-22 (assuming a ±15 degree viewing band about the normal). Figure III-23 shows the cumulative percentage of area of the celestial sphere exposed to a ±15 degree viewing band and a ±30 degree viewing band as a function of the number of days the spacecraft has been in orbit performing viewing activities.

The ±15 degree viewing band curve shows that during the first day in orbit, the Observatory will have 32 percent of the celestial sphere accessible to it for viewing. Further, this curve shows that during the 30.4, 60.9, 91.3, 121.7, and 152.1 days in orbit the Observatory will have had, respectively, 47, 63, 77, 91, and 100 percent of the area accessible for viewing. The ±30 degree curve indicates how the cumulative percentage of exposed area increases as a function of viewing band width.

Implied in this curve is the fact that doubling the width of the access band does not reduce to half the time required to cover the entire celestial sphere. As indicated, only 30 days are gained by doubling the viewing bandwidth.

(5) Number of Days Required for Spacecraft Access Bands to Reach a Source. The time required for the ±15 degree access bands of the HEAO to reach a target primarily depends upon the location of the sun in the ecliptic plane. For a general case, consider the sun located in the ecliptic plane as indicated in Figure III-22. The ecliptic plane is shown in this figure as its projection on the celestial equator. Based upon this celestial longitude of the sun, the length of time required for the viewing bands of the spacecraft to reach a target as a function of the celestial longitude (celestial latitude $\phi = 0$

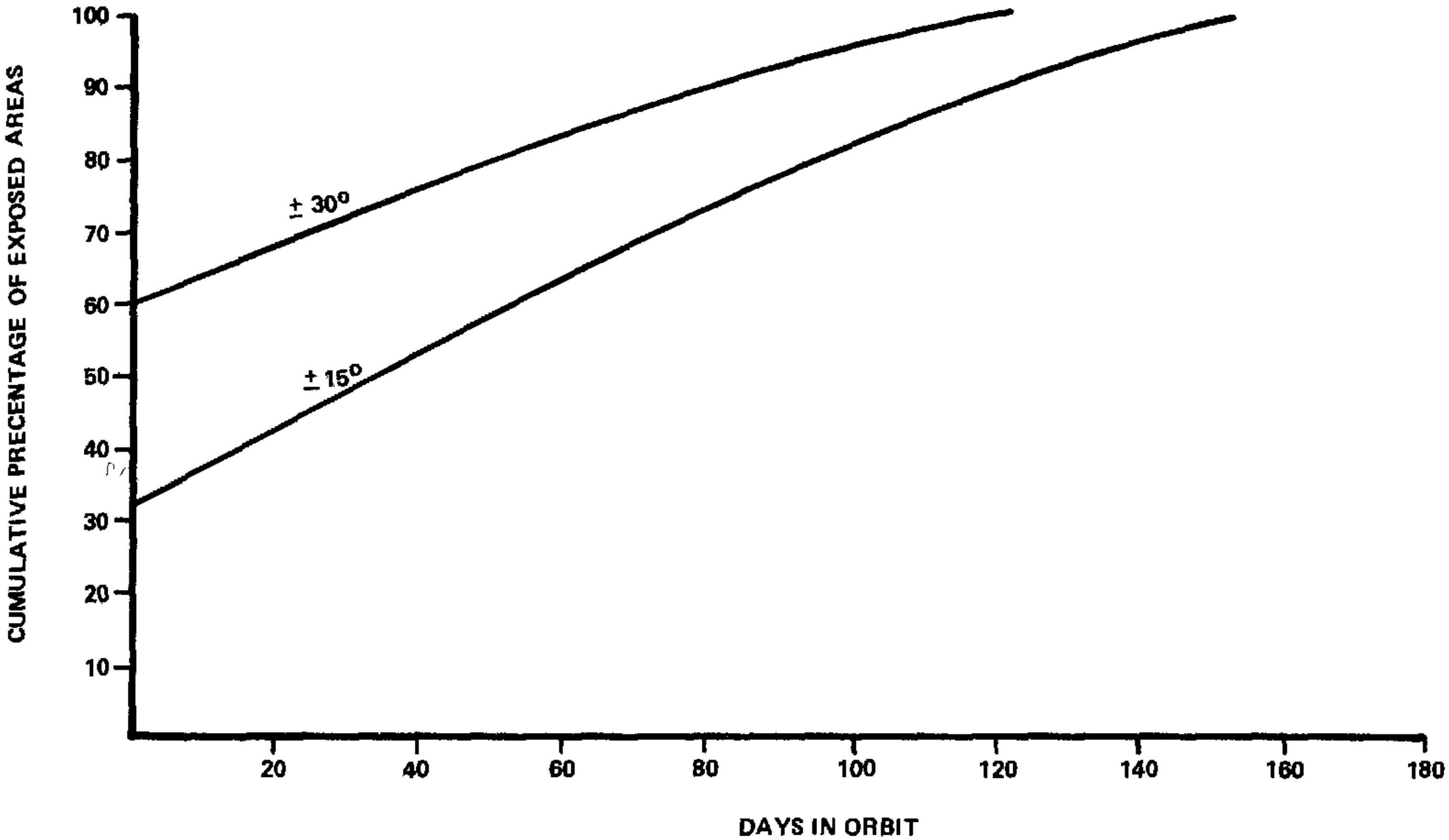

Figure III-23. Cumulative percentage of area exposed to ±15 degree and ±30 degree viewing bands.

degrees) of the source is shown in Figure III-24. Specifically, this curve shows that sources whose celestial longitudes are between 75 degrees and 105 degrees, coupled with those whose celestial longitudes are between 255 degrees and 285 degrees are available for observation during the first day in orbit.

In contrast to this, the curve in Figure III-24 shows, also, that the viewing of those sources whose celestial longitudes are 74.9 degrees and 254.9 degrees will require approximately 152 days in orbit based upon the March 21 situation shown in Figure III-23.

(6) Date to View a Given Point. A zero degree cone angle of the spacecraft's spin axis will allow two opportunities per year to view a particular target source with a short duration, in one day, of viewing time associated with both opportunities. The fifteen degree cone angle will allow a range of opportunity centered about the date derived from the zero cone angle.

Figure III-25 gives dates on which a source with a given longitude can be viewed assuming a zero angle of the spacecraft's spin axis. The viewing date is not dependent upon the source's latitude; for a given longitude all latitudes are available in the viewing plane. But the solution for the viewing dates in the equatotial system is dependent on the source's declination, and it is not as easy to work with data from the equatorial system as it is with the data presented in the ecliptic system.

(7) Maximum Number of Days a Source Will Remain Within the Spacecraft Viewing Bands. An important parameter that must be considered when defining a mission whose objectives are similar to those of the HEAO is the length of time a source will be accessible for observation and study. From a scientific point of view, this is one of the most important parameters of the entire mission. Figure III-26 presents this parameter (actual days target is accessible) per 180 days in orbit as a function of the target's absolute value of latitude (ϕ). Latitudes near zero require the rotation plane to be nearly 90 degrees inclined to the ecliptic. As a result of this, the ±15 degree curve shows that sources located at 0 degrees celestial latitude can be viewed for only 30.4 days per 180 days in orbit and those located between ±75 degrees and 90 degrees celestial latitude (ϕ) can be viewed during the entire mission. It is significant that those sources which are located between ±75 degrees and 90 degrees are said to be within the circle of total access (COTA). The COTA is a function of the width of the viewing band and represents the area on the celestial sphere of a circle whose radius is one-half of the width of the viewing band utilized.

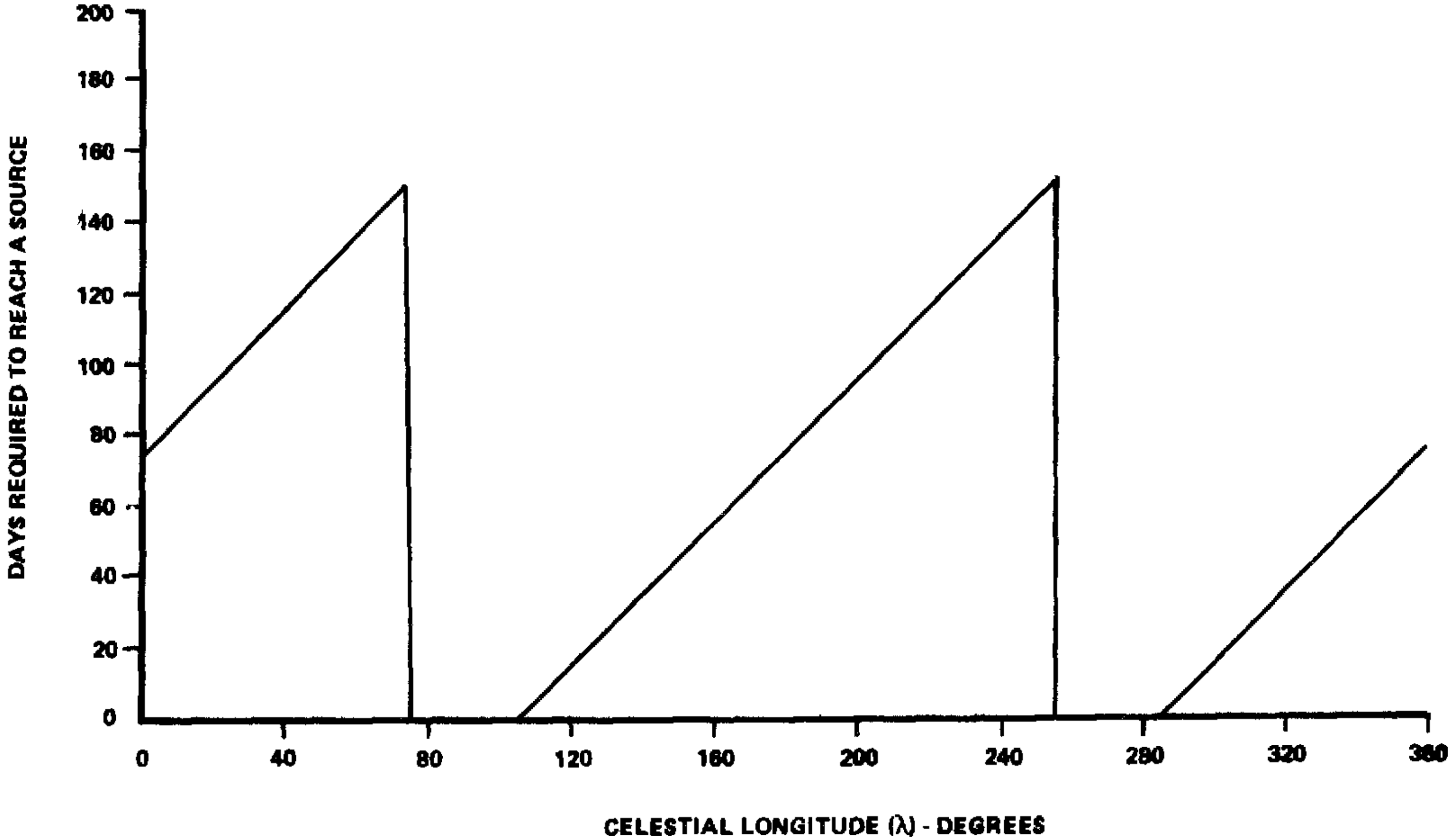

Figure III-24. Number of days required for viewing band to reach a source.

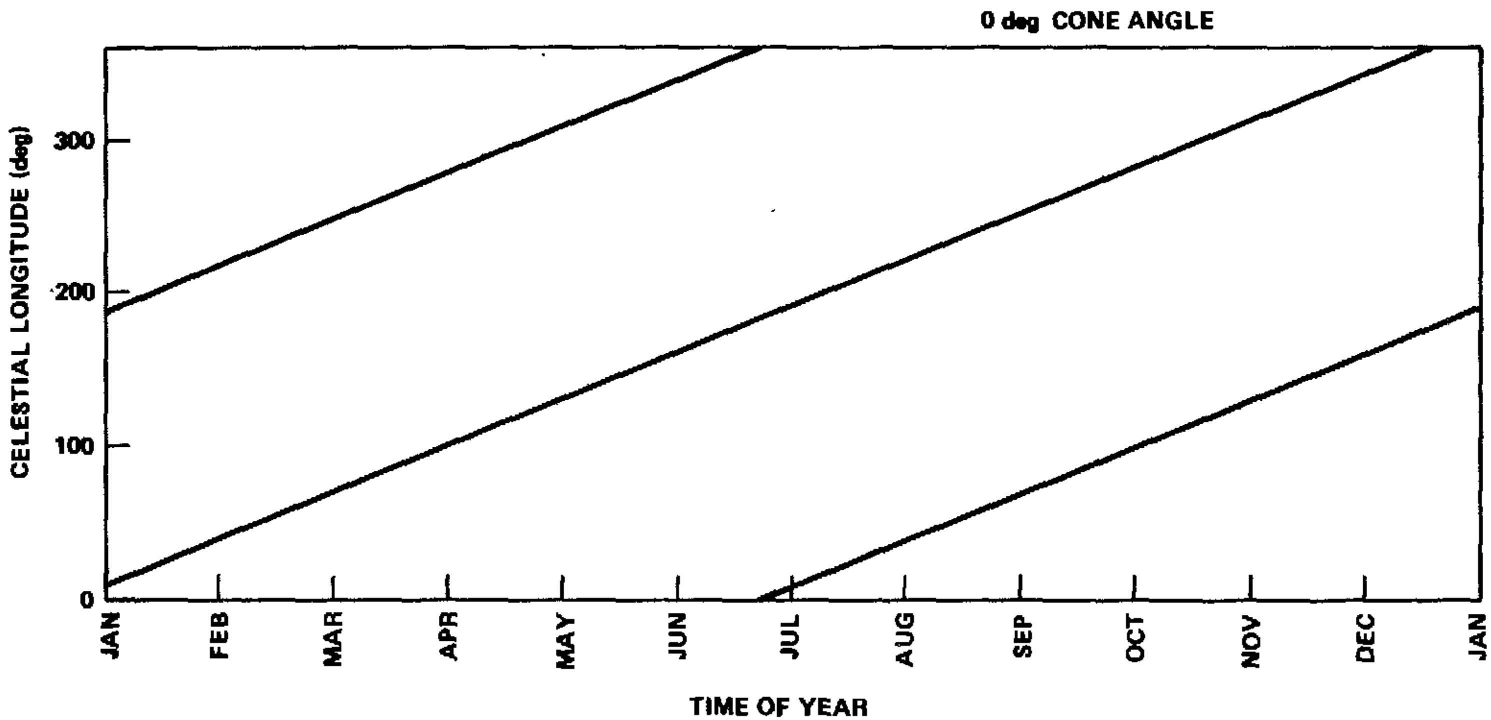

Figure III-25. Time of the year to view a given point, ecliptic system.

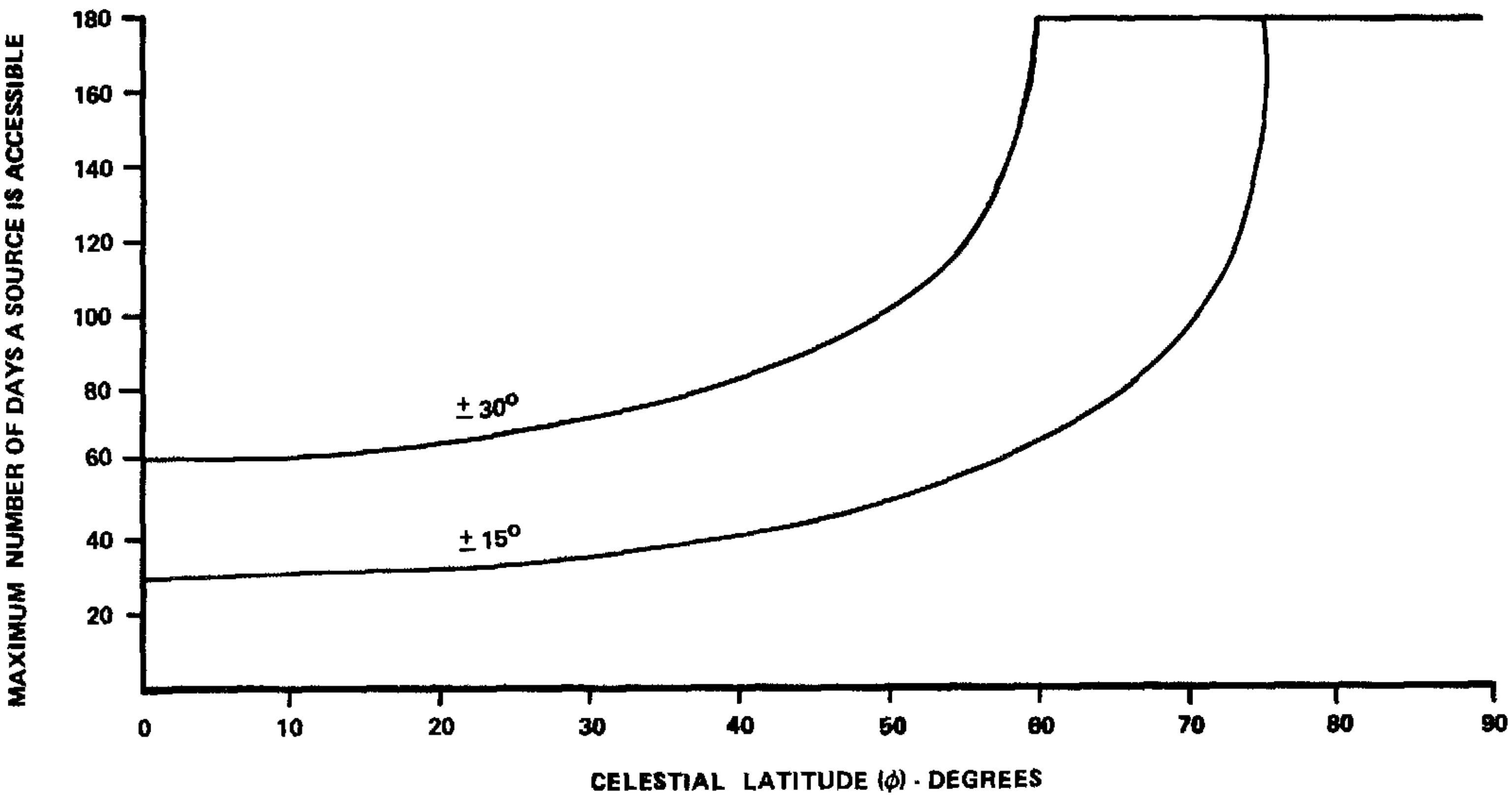

Figure III-26. Maximum number of days a source is accessible per 180 days in orbit.

The ±30 degrees is presented to show how the number of days a source will remain within the spacecraft's access band increases as the access bandwidth increases.

3. HEAO Viewing and Target Acquisition Time Capability. As the HEAO spacecraft orbits the earth, in a period of time of approximately 94 minutes, its solar panels will be occulted by the earth at a maximum of approximately 37 minutes of this time. During these 37 minutes the spacecraft can ignore the constraint that its solar axis must be maintained within a 15 degree half-cone in a direction perpendicular to the sun and, consequently, point to any sources on the celestial sphere which are not blocked by the earth. The capability for ±15 degree and ±30 degree access bandwidths based upon an altitude of 270 n.mi. is shown in Figure III-27. This capability is presented in terms of source viewing time (hours/day) as a function of the target's location for one day, as shown in the insert in Figure III-27. The ±15 degree curve shows that sources located between 75 degrees and 105 degrees, in addition to these located between 255 degrees and 285 degrees, can be viewed considerably longer than sources at other locations. This is because the spacecraft can view these sources during the off-nominal mode as well as during the nominal mode. The combination of the nominal viewing time and the off-nominal viewing time gives rise to the capability of viewing these sources for considerable length of time per day.

Figure III-28 shows that during the time of one day in orbit for the location of the sun, as shown in the insert, the spacecraft can reach sources located between 22 degrees and 338 degrees. This implies that after 43 days in orbit, the spacecraft will have had access to the entire celestial sphere.

To determine the accessibility of these possible target sources positioned near the galactic plane, a list of 91 sources and their coordinates for these sources where taken from Reference III-7. The impact of 0 degree and 15 degree viewing angles of the spacecraft was considered in determining the accessibility of the targets.

A zero degree cone angle for the HEAO spacecraft spin-axis was considered in determining the viewing opportunity of the 91 sources. The time when these sources could be viewed is shown in Figure III-29. During most of the year, only one source is available on a given day; however, in the month of March many of the sources are within the viewing plane when as many as six sources can be seen during a day. This fact is also brought out in Figure III-21 where a large number of sources are seen to be near a longitude of 270 degrees. There are many days when there are no sources within viewing range. The viewing profile given in Figure III-29 will repeat every six months.

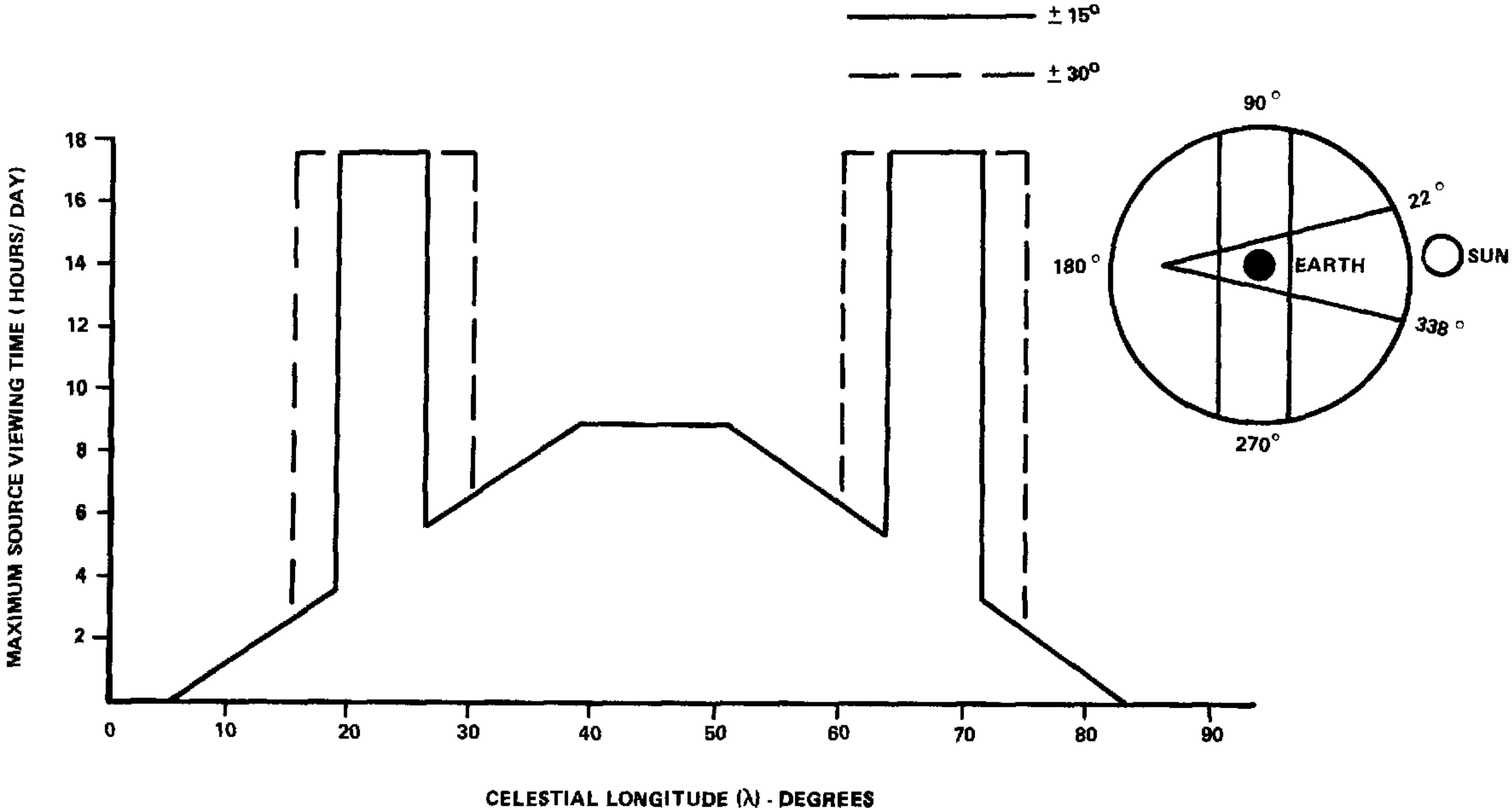

Figure III-27. Maximum source viewing time.

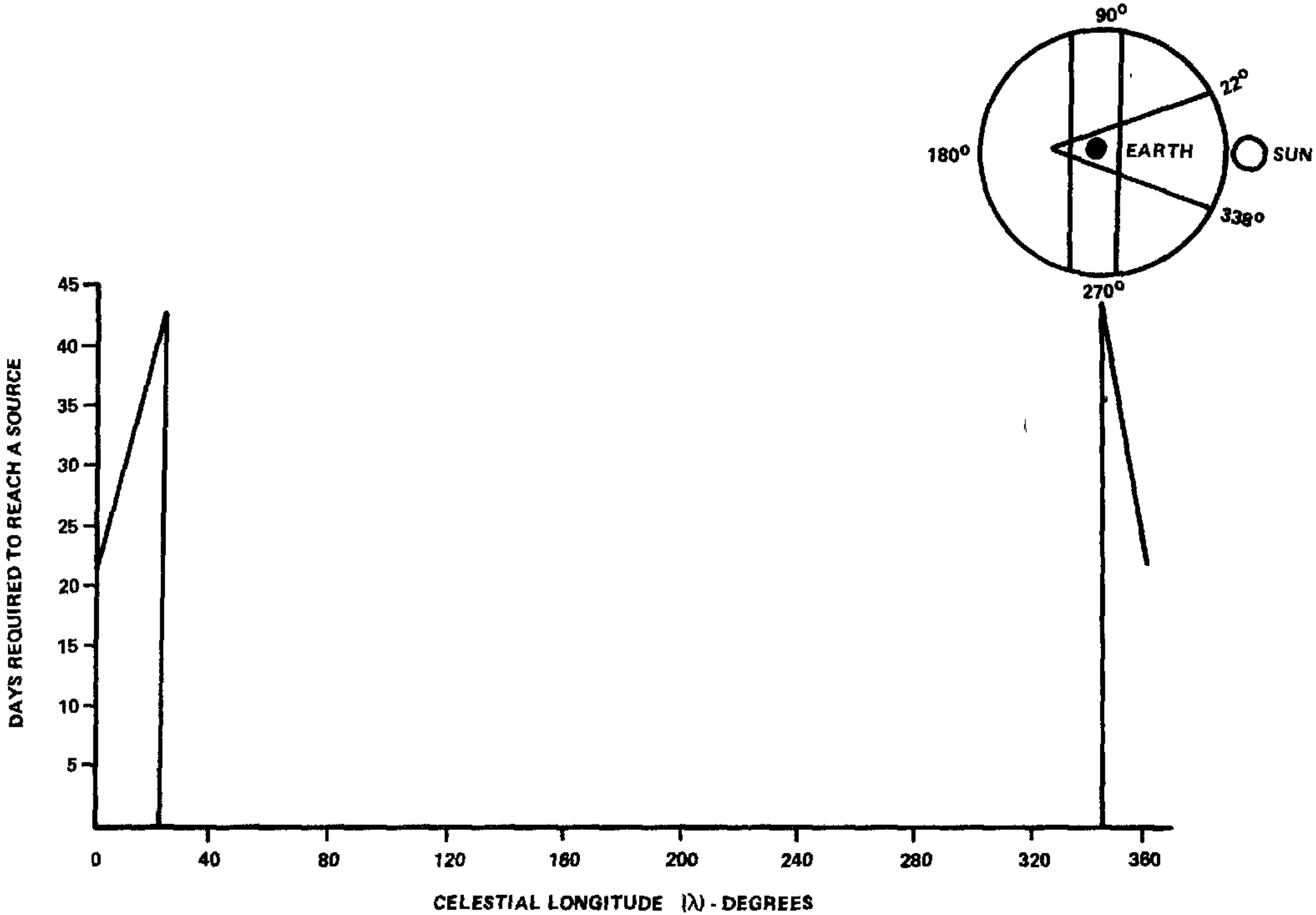

Figure III-28. Number of days required to reach a source.

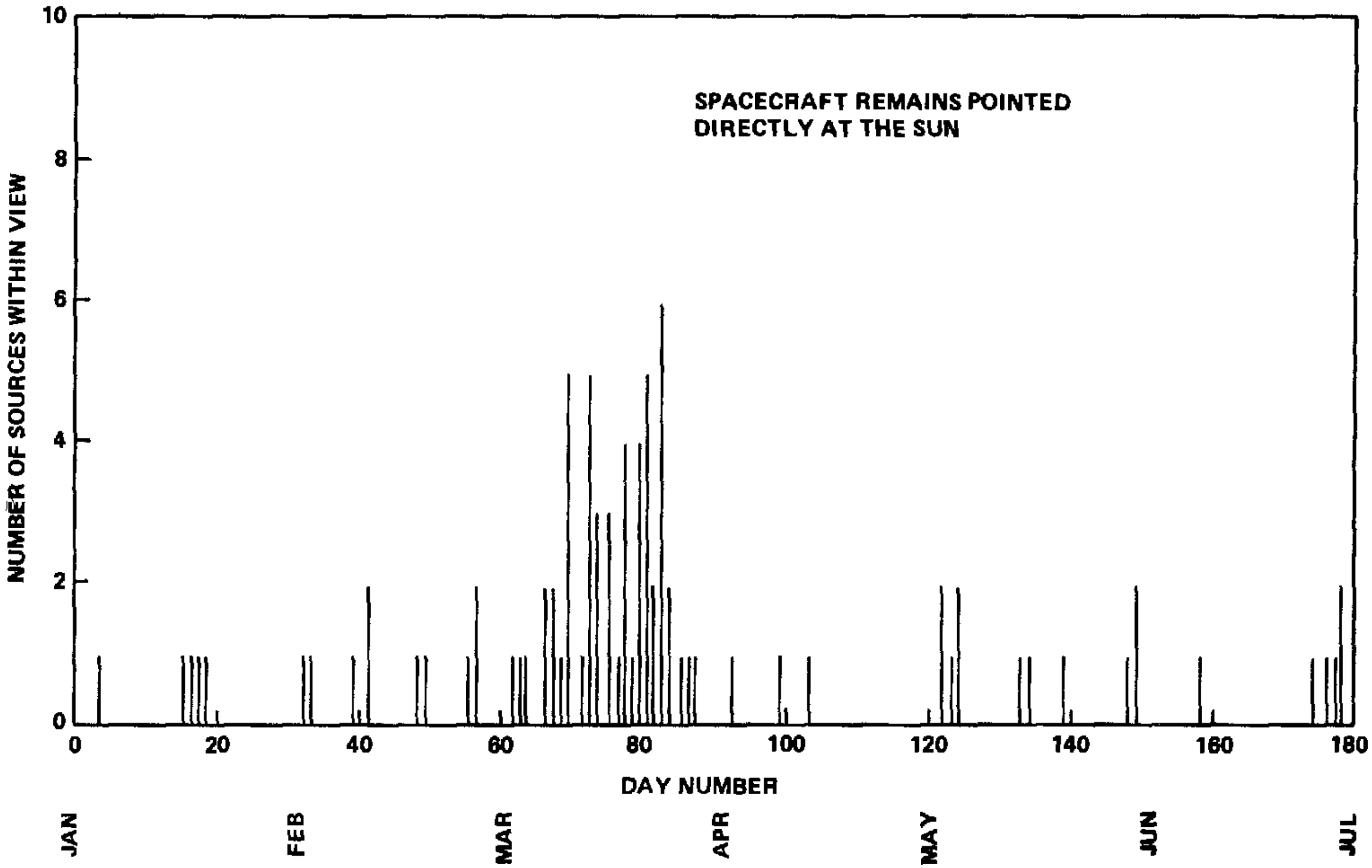

Figure III-29. Number of sources able to be viewed by HEAO, 0 degree cone angle.

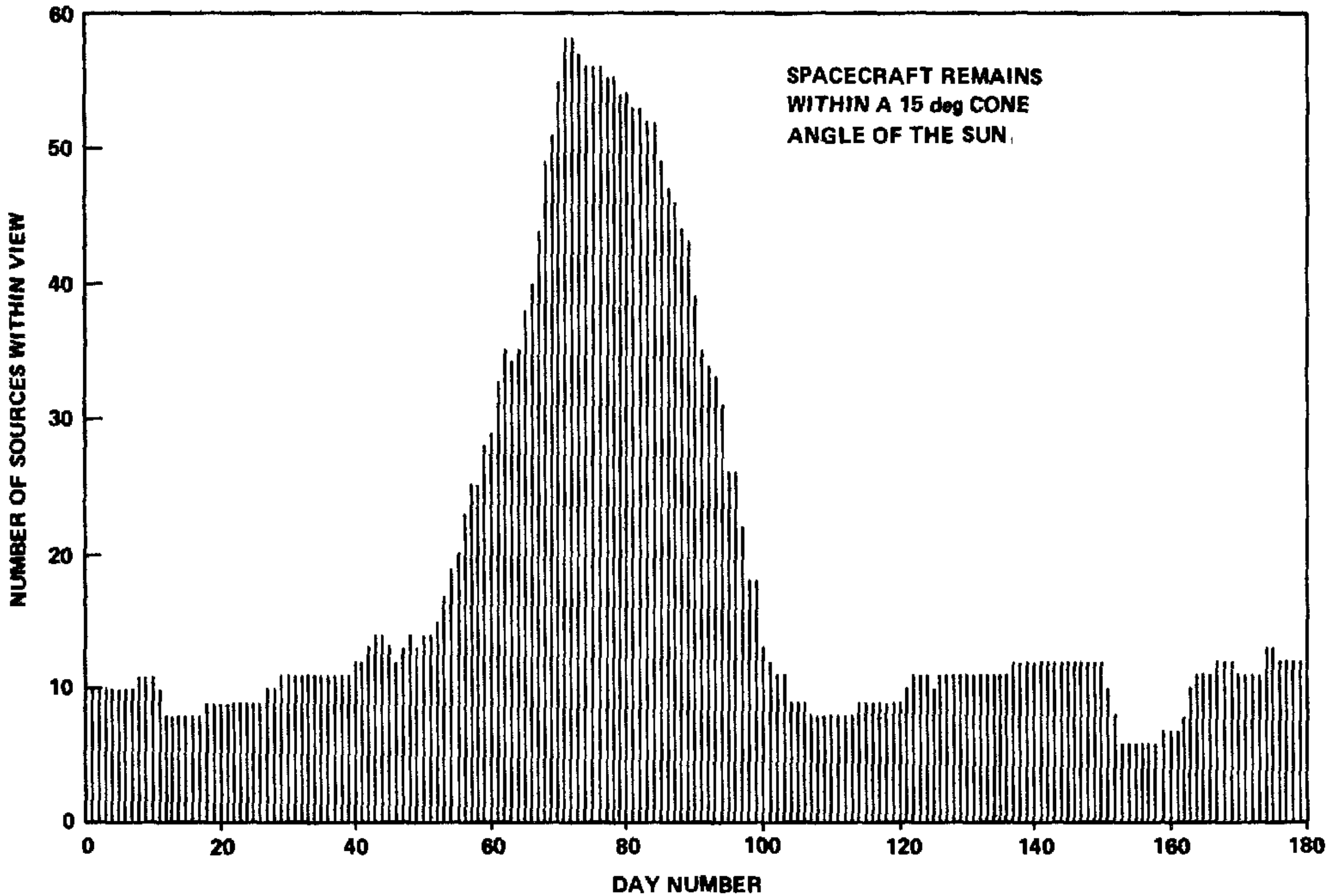

Figure III-30. Number of sources able to be viewed by HEAO, 15 degree cone angle.

Viewing accessibility for the 91 sources listed in Reference III-7 were determined for an off-solar angle of 15 degrees. This information is given in Figure III-30. During most of the year there are approximately 10 sources available per day within the 15 degree pointing limit. However, during the month of March and up to mid-April and again during the month of September and up to mid-October there are a large number of sources available for data gathering. A peak of 58 sources are within viewing range on March 21; these source positions are illustrated in Figure III-21. The viewing disk of June 21 is given in Figure III-31; here it is shown that only about 10 sources are available for potential monitoring.

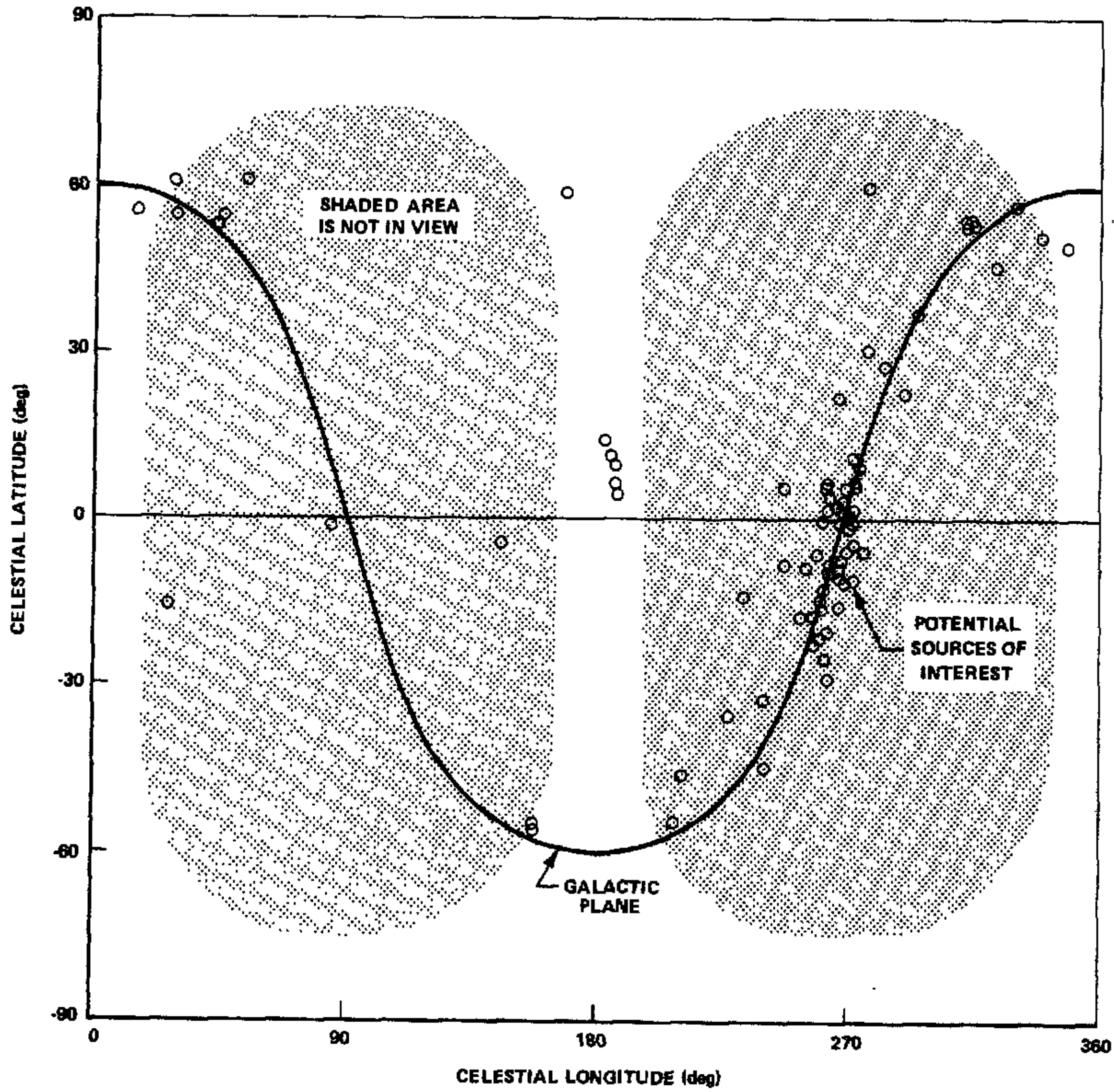

Figure III-31. Areas within view on 21 June.